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Supplier Selection Using Sustainable Criteria in Sustainable Supply Chain Management

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Abstract**—**Selection of suppliers is a crucial problem in the supply chain management. On top of that, sustainable supplier selection is the biggest challenge for the organizations. Environment protection and social problems have been of concern to society in recent years, and the traditional supplier selection does not consider about this factor; therefore, this research work focuses on introducing sustainable criteria into the structure of supplier selection criteria. Sustainable Supply Chain Management (SSCM) is the management and administration of material, information, and money flows, as well as coordination among business along the supply chain. All three dimensions - economic, environmental, and social - of sustainable development needs to be taken care of. Purpose of this research is to maximize supply chain profitability, maximize social wellbeing of supply chain and minimize environmental impacts. Problem statement is selection of suppliers in a sustainable supply chain network by ranking the suppliers against sustainable criteria identified. The aim of this research is twofold: To find out what are the sustainable parameters that can be applied to the supply chain, and to determine how these parameters can effectively be used in supplier selection. Multicriteria decision making tools will be used to rank both criteria and suppliers. AHP Analysis will be used to find out ratings for the criteria identified. It is a technique used for efficient decision making. TOPSIS will be used to find out rating for suppliers and then ranking them. TOPSIS is a MCDM problem solving method which is based on the principle that the chosen option should have the maximum distance from the negative ideal solution (NIS) and the minimum distance from the ideal solution.

Keywords**—**Sustainable supply chain management, supplier selection, MCDM tools, AHP analysis, TOPSIS method.

I. Introduction

ORGANIZATIONS are increasingly getting aware of importance social and environmental factors. The number of organizations considering environmental practices into their strategic proposals and operations is continuously increasing [1]. Innumerable techniques are introduced for organizations to become more accountable both environmentally and socially. The notions concerning supply chain environmental management (SCEM) or greening the supply chain implies screening suppliers on grounds of their environmental performance and doing business only if they meet regulatory standards [2]. Conventionally, organizations consider criteria like initial price and quality level for supplier selection and evaluating supplier performance. With increasing consciousness about sustainability in organizations, suppliers are being selected according to sustainability criteria [6]-[8]. Also, sustainable activities decide the suppliers' sustainable performance. For the selection of best suppliers, decision makers (DMs) need to set important criteria and verify supplier performance on the basis of that. In real life scenario, problems need to be evaluated on multiple criteria and alternatives. Such problems are called multi-criteria decision making (MCDM) problems. MCDM problems need DMs to measure the performance of different supplier alternatives with respect to all the verified criteria, while keeping in mind the significance of verified criteria with respect to the problems' final objective. Selection of criteria and evaluation of suppliers on the basis of these criteria is considered as a type of MCDM problem which is complicated and needs certain algorithms or tools for solutions. [10]. In this research two MCDM tools are used i.e. AHP and TOPSIS method. In AHP, different criteria are given a rating on the basis of their importance. Here, information is decomposed into a hierarchy of alternative and criteria and then integrated to determine relative ranking of alternatives [9]. In TOPSIS measurement of importance weight of criteria and preferences of each alternative with respect to criteria are determined by crisp numbers. TOPSIS is an MCDM problem solving method which is based on the principle that the final alternative should have the maximum distance from the NIS and the minimum distance from the ideal solution (PIS). NIS maximizes the cost criteria and minimizes the benefit criteria; PIS vice versa.

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II. Literature Survey

A. Sustainable Supply Chain Management

Supply chain management comprises of each and every stage from raw material procurement to the final delivery of products or good to the customer [12]. Carter and Rogers provided the following definition of SSCM as "the planned combination and integration of company's three dimensional goals i.e. social, environmental, and economic to improvise the long-term economic performance of business and elements of its supply chains" [3]. Similar definition proposed by Seuring and Muller where SSCM is defined as "the management of raw material, information and money flow among organizations along the complete supply chain while ensuring goals from all three dimensions are met for sustainable growth i.e., economic, environmental and social. [23] Environmental and social criteria demand to be met by the members and stakeholders to remain within the supply chain, while it is obviously expected that competitiveness

would be there and there will be an extra edge for having met customer needs and economic goals" [4].

B. Importance of Economic Criteria

Economic criteria focus on the primary purpose of the organizations i.e. to gain higher profits. Like traditional supply chain management, the focus is on higher profitability. It can be achieved by reducing costs in different areas, reducing idle time etc. It includes criteria like Productcost, ordering and logistic cost, inventory cost, custom and insurance cost. Product rejection rate, quality certificates and belts i.e. Lean six sigma belts, quality management, capability of handling mishaps. It also includes factors like cost of environmentally friendly packaging and cost for disposal of waste for three dimensional development. Lead Time and On Time Delivery Time between procurement and delivery of an order, lags in delivery schedule. [10].

C. Importance of Social Criteria

Because of increased awareness manufacturing corporations have started concentrating on problems such as safety, working conditions, operations, wages, child labor, human rights and poverty [16]. Pressure from management and stakeholders are forcing corporations to be socially accountable. They want companies to include social criteria like Health and Safety Practices: Occupational health and safety programs, education, training, counseling, prevention, and risk-control programs in situ to assist work force members or community members regarding serious diseases [19], [20]. Social Responsibility: Supporting short term and long term social projects, supporting institutional establishments, grants and donations. Educational Infrastructure: Programs for skills management and lifelong learning that support the continued employability of workers and assist them in managing career endings. Employment Practices: Worker relations, human rights and worker interests, flexible working facilities, working conditions and abolition of child labor, equity of labor sources, diversity and discrimination. Few more criteria that can be considered are daily recreational needs, life strategies, emotional well being, and activities to retreat against stress, sports facilities, and family or community events [9], [13]-[15].

D. Importance of Environmental Criteria

Due to increasing awareness about environmental degradation, manufacturing companies and customers both are becoming alert of environment protection [17]. This has led stakeholders of companies to ensure safe practices like pollution control, reuse, recovery etc. It has many positives like: Improved business and public image, attraction of environmentally aware customers, Improved quality etc. [11], [18]. It includes criteria like Pollution Control: Air emissions, wastewater, solid wastes and use of harmful materials. Resource Consumption of raw materials, energy and water. Green Product and Eco-design: Use of environmentally friendly technology and materials, design capability for reduced consumption of material/energy, reuse, recycle of material, design of products to avoid or reduce use of harmful materials, green packaging. Environmental Management System: Environment related certificates like ISO 14001, environmental policies, checking and control of environmental processes. [5] To reduce the harm to the environment, organizations should also consider factors like permit requirements, compliance requirements, strategic considerations, climatic considerations and government policy. [10]

III. Methodology

In this case study, all the criteria and suppliers will be ranked using MCDM tools. Multiple- criteria decision-making is a branch of operations research which concerns solving problems explicitly considering multiple criteria. In real life problems, there are many conflicting factors that need to be weighed for making any decision. Economic criteria i.e. cost is usually one of the main criteria [10]

AHP Analysis helps to rate the significant criteria identified. It is a technique used to measure the qualitative factors like judgments, feeling, emotions and quantitative factors like cost, price etc. in decision making. In this approach, different criteria are given a rating on the basis of their importance. Here, information is decomposed into a hierarchy of alternative and criteria and then integrated to determine relative ranking of alternatives. In the decision making of AHP, four steps are involved. Firstly, problem and objective is specified. Secondly, criteria are defined. Thirdly, sub criteria and alternative decisions are made. Fourth is the conclusion or the final decision. Its application areas are strategic planning, resource allocation, source selection, program selection, business policy etc. [9].

TOPSIS is Technique of Order Preference by Similarity to PIS. This method considers qualitative, quantitative and cost criteria. This method is mathematically quite simple as compared to other MCDM tools. Other advantage of this approach is that it offers flexibility in the definition of alternatives or choice set. TOPSIS method is used to find out rating for suppliers and then ranking them. In TOPSIS, crisp numbers are used to measure importance of each criterion and alternative's preferences [21], [22]. TOPSIS is a MCDM tool which works on the principle that the chosen alternative should be the closest possible option from the PIS and the farthest possible option from the NIS. NIS maximizes the cost criteria and minimizes the benefit criteria; PIS vice versa [10].

IV. Procedure

A. Identifying Supplier Criteria

TABLE I
IDENTIFYING SUPPLIER CRITERIA

Type of criteria	Criteria
Economic	Initial price, cost for disposal of waste, cost for environmental friendly packaging
Social	Discrimination in employment, child labor, health and safety of staff and customers, harassment
Environmental	Reuse of materials, recycling of materials, raw material quality, pollution/wastage

B. Industrial Survey

A Questionnaire form was circulated in industries to find out how much weight age is given to the listed criteria. Following weight age is given to them: 1 Equal; 3 Moderate; 5 Strong; 7 Very Strong; 9 Extreme. Following are the donations: *Ec1* Initial Price; *Ec2* Cost for disposal of waste; *Ec3* Cost for environmental friendly packaging; *S1* Discrimination in employment; *S2* Child Labor; *S3* Health and safety of staff and customers; *S4* Harassment; *En1* Reuse of materials; *En2* Recycle of materials; *En3* Pollution/Wastage; *En4* Raw material quality.

	Ec1	Ec2	Ec3	S1	S2	S3	S4	En1	En2	En3	En4
Ec1	1			5	9	5	9	7	3	7	3
Ec2	5	1	2	5	7	5	7	6	6	2	
Ec3	5		1	5	7	5	7	6	6	2	
S1				1	5	5	5				
S2					1			3	3	2	2
S3					3	1	4				
S4					3		1				
En1				3		4	7	1		6	
En2				3		4	7	2		6	
En3				2		6	7			1	
En4		5	5	3		4	7	5	5	7	1

Fig. 1 Results of questionnaire form in matrix format

C. AHP Analysis

Step 1: Making the criteria weight age matrix.

	Ec1	Ec2	Ec3	S1	S2	S3	S4	En1	En2	En3	En4
Ec1	1	0.20	0.20	5	9	5	9	7	3	7	3
Ec2	5	1.00	2	5	7	5	7	6	6	2	0.20
Ec3	5	0.50	1.00	5	7	5	7	6	6	2	0.20
S1	0.20	0.20	0.20	1.00	5	5	5	0.33	0.33	0.50	0.33
S2	0.11	0.14	0.14	0.20	1.00	0.33	0.33	3	3	2	2
S3	0.20	0.20	0.20	0.20	3	1.00	4	0.25	0.25	0.17	0.25
S4	0.11	0.14	0.14	0.20	3	0.25	1.00	0.14	0.14	0.14	0.14
En1	0.14	0.17	0.17	3	0.33	4	7	1.00	0.50	6	0.20
En2	0.33	0.17	0.17	3	0.33	4	7	2	1.00	6	0.20
En3	0.14	0.50	0.50	2	0.50	6	7	0.17	0.17	1.00	0.14
En4	0.33	5	5	3	0.50	4	7	5	5	7	1.00

Fig. 2 Criteria matrix

Step 2: Squaring the matrix.

1	0.04	0.04	25	81	25	81	49	9	49	9
25	1	4	25	49	25	49	36	36	4	0.04
25	0.25	1	25	49	25	49	36	36	4	0.04
0.04	0.04	0.04	1	25	25	25	0.1111111	0.1111111	0.25	0.1111111
0.012345679	0.0204082	0.0204082	0.04	1	0.111111111	0.111111111	9	9	4	4
0.04	0.04	0.04	0.04	9	1	16	0.0625	0.0625	0.027777778	0.0625
0.012345679	0.0204082	0.0204082	0.04	9	0.0625	1	0.0204082	0.0204082	0.020408163	0.0204082
0.020408163	0.0277778	0.0277778	9	0.111111111	16	49	1	0.25	36	0.04
0.111111111	0.0277778	0.0277778	9	0.111111111	16	49	4	1	36	0.04
0.020408163	0.25	0.25	4	0.25	36	49	0.0277778	0.0277778	1	0.0204082
0.111111111	25	25	9	0.25	16	49	25	25	49	1

Fig. 3 Squared Criteria matrix

Step 3: Finding row sums and normalizing them. This is a continuous process and is carried out until the difference between 2 consecutive normalized row sums is negligible.

Step 4: Finding final normalized sums. These are the final weight age given to each criterion.

TABLE II
CRITERIA WEIGHTAGES

	w_j
Ec1	0.21706
Ec2	0.16757
Ec3	0.16509
S1	0.05059
S2	0.01802
S3	0.0174
S4	0.00675
En1	0.07353
En2	0.07606
En3	0.05992
En4	0.014799

D. TOPSIS Analysis

Step 1: Construct decision matrix.

TABLE III
DECISION MATRIX

	Ec1	Ec2	Ec3	S1	S2	S3	S4	En1	En2	En3	En4
S1	9	8	8	6	7	5	7	6	5	8	4
S2	7	6	7	5	6	7	6	7	4	9	5
S3	5	6	7	5	5	7	5	8	4	8	6

Step 2: Square the matrix and calculate column sum $\sum X^2$ and then its square root $\sqrt{\sum X^2}$

81	64	64	36	49	25	49	36	25	64	16
49	36	49	25	36	49	36	49	16	81	25
25	36	49	25	25	49	25	64	16	64	36
155	136	162	86	110	123	110	149	57	209	77
12.4499	11.6619	12.7279	9.273618495	10.48808848	11.09053651	10.48808848	12.2066	7.54983	14.45683229	8.77496

Fig. 4 Squared Decision Matrix

Step 3: Divide each column of initial matrix by $\sqrt{\sum X^2}$ to get r_{ij}.

Step 4: Multiply each column by w_j to get v_{ij}.

Step 5: Mark the ideal and negative ideal solution.

Step 6: Determine separation of normalized matrix from ideal solutions. $Si^* \equiv \sqrt{\sum (Vj^* - Vij)^2}$

Step 7: Determine row sums and then find S_i^*

Step 8: Determine separation from NIS. $Si' \equiv \sqrt{\sum (Vj' - Vij)^2}$

Step 9: Determine row sums and then find S'

Step 10: Calculate relative closeness to the ideal solution.

$$C^* \equiv \frac{S'}{S'+S^*}$$

TABLE IV
SEPARATION FROM IDEAL MATRIX

	S*
S1	0.0778485
S2	0.0404501
S3	0.0352212

TABLE V
SEPARATION FROM NEGATIVE IDEAL MATRIX

	S'
S1	0.034984
S2	0.0507771
S3	0.0777415

TABLE VI
RELATIVE CLOSENESS FACTOR

	S'	S*	S'+S*	C*
S1	0.034984	0.0778485	0.11283	0.3100
S2	0.0507771	0.0404501	0.01923	0.5566
S3	0.0777415	0.0352212	0.11296	0.6882

TABLE VII
CONCLUSIONS BASED ON RELATIVE CLOSENESS FACTOR

	C*	Results
S1	0.3100	Worst
S2	0.5566	
S3	0.6882	Best

V. Results and Discussion

Value of C* signifies relative closeness factor. It denotes closeness of the value to the ideal solution and the distance from NIS. Therefore, C* denotes how well does a supplier take care of the listed criteria. i.e. environmental, economic & social. We will always choose the Supplier with highest C*to:

- Maximize profit
- Maximize social wellbeing
- Minimize environmental effects.

Therefore, ranking of suppliers is as: Supplier 3: First Supplier, 2: Second Supplier, 1: Third.

VI. Conclusion

Supplier 3 has the largest value of C* and is thus the best supplier and satisfies the criteria best. Supplier 1 has the smallest value of C* and is thus the worst supplier amongst the three. *Ranking of Suppliers*: *Supplier 3: First; Supplier 2: Second; Supplier 1: Third*. Suppliers are becoming an essential part of a larger value chain network. Many a time, unfair actions of suppliers impact the corporate image and firm significantly. Supplier selection in emerging economies is a foremost decision that stakeholders and management need to make to have a deliberate advantage over rest. In future, their significance will increase even more so there is an urgent need to develop and adopt strategies which helps organizations to recognize best suppliers. In this research, MCDM tools are used to find out the rating or criteria and then find out ranking of suppliers. AHP analysis is used to find rating of criteria and TOPSIS method is used to find ranking of suppliers. MCDM tools like AHP and TOPSIS can be used in industries and organizations to easily find the suppliers which prove to be the best in all the three sectors i.e. Environmental, Economic and social. This will improve the productivity and effectiveness of the organization, at the same time, it will minimize the costs. This research addresses the need for social and environmental sustainability in business, especially in the supply chain. Though social and environmental sustainability parameters in the supply chain are not very prevalent, with this new model, industries will be able to incorporate them in evaluation and partner selection.

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